NXP RF Solid State Cooking White Paper

Robin Wesson, System Architect, NXP RF Power Innovation

1 SUMMARY

Microwave oven technology is on the cusp of a revolution. Solid state electronics can now deliver comparable power levels to the magnetron which has been the engine of the microwave oven since the first products were launched seventy years ago. The new technology brings with it many new techniques that can significantly enhance the control of energy delivery. These techniques represent scope for innovation that will change the user's experience of cooking with high power RF energy. The technical implications and possibilities are examined in this paper which should be of interest to engineers or food scientists keen to improve the results achievable with industrial or consumer RF heating appliances.

2 BACKGROUND

Since the 1950's the humble transistor has all but totally replaced electronic vacuum tubes, (valves), in electronics applications. The transistor is the driving force behind ubiquitous computing and communication capabilities beyond our imagination just a decade or two ago. Moore's famous 'law' has observed that the number of transistors per square mm of silicon has doubled year on year, delivering an exponential increase in processing power. This growth is responsible for ever more powerful computers, handheld devices, highly efficient and clean engine control systems, medical instrumentation, gaming platforms and a plethora of other electronic systems touching every aspect of our lives today.

Not all transistors are better when small, however. A single large device can switch currents of hundreds of amps, or broadcast television and radio signals around the world, and even beyond it. High power transistors, while not the subject of Moore's law, have gradually increased in efficiency, power density and voltage capability through many generations of technology development, and can now compete with one of the last valve applications that very few people realise they still have in their own home.

3 THE MAGNETRON

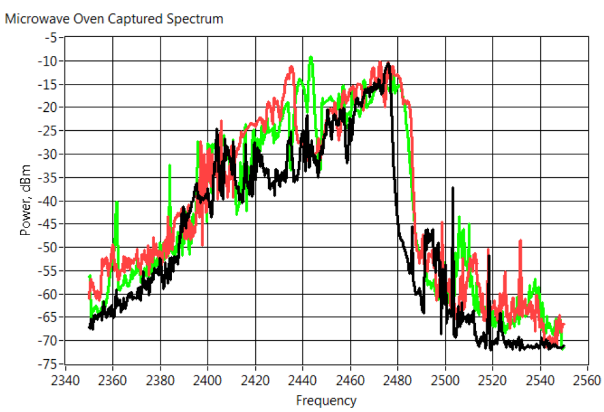
The magnetron is the heart of every microwave or combination oven in use today. The magnetron is a type of valve integrated with magnets and resonant chambers which generates a high power RF signal used for cooking, heating and drying in consumer and industrial applications.

Discovered early in the last century, the magnetron design was improved and applied during the 1940's for radar applications. Over time, the design has been perfected and the magnetron now delivers high power with good efficiency and at relatively low cost. For cheap raw power, the magnetron remains a great solution.

Radar applications have evolved beyond use of the magnetron, because the signals it generates cannot deliver the accuracy and control needed for high performance measurement systems. Frequency is approximate and dynamic, and accurate control of amplitude or phase is not possible. The entire communications industry also relies on accuracy of modulation and for these reasons a better solution was required.

In contrast, much of the innovation in microwave cooking in recent decades has been in food additives and meal packaging techniques designed to give the best results with the existing heating technology. (IMPI conference 2013, Providence, RI). A regular complaint aired was that an additive, special recipe or innovative package that delivered good performance in one oven would do something different in another example of the same kind of oven. Variability from one test to another was claimed to be too great.

The root cause of these complaints is the variability of the engine of the microwave oven. High performance microwave cooking requires a new approach.



Magnetron spectral emissions in microwave oven operation – 3 traces of 30 seconds captured from same oven with the same load.

4 THE MICROWAVE COOKING EXPERIENCE

Most of us are familiar with the results: microwave ovens deliver rapid heating but can result in food with overcooked, dehydrated parts and cold or raw parts. For these reasons microwaves are not widely trusted to cook raw meats, and are often used simply to reheat leftover food, or perhaps to heat a mug of water or milk quickly for making a hot drink.

It is fair to say that with a little ingenuity, many more foods can be heated quite well in a microwave. A spoonful of water in a covered bowl of broccoli or sliced carrots creates a fast steamed vegetable side dish that is well cooked and nutritious. Combining the use of a microwave at low power, with a grill or hot air system it is possible to create meat dishes with pleasing surface texture and taste, cooked in around half the time compared to a conventional oven.

Regardless of the energy source, be it magnetron or solid state amplifier, the electromagnetic energy interacts with the cavity to create patterns of standing waves that are responsible for the simultaneously overcooked and raw food recognisable to our typical user. Solid State does not eliminate the existence of hot spots.

The interaction of electromagnetic energy with the food is also unchanged. Electromagnetic energy is absorbed by food depending on the frequency used and the dielectric properties of the food. In most foods, contrary to the urban myth of heating from the middle, consumer microwave ovens operating around 2450MHz directly heat only to a depth of a couple of centimetres.

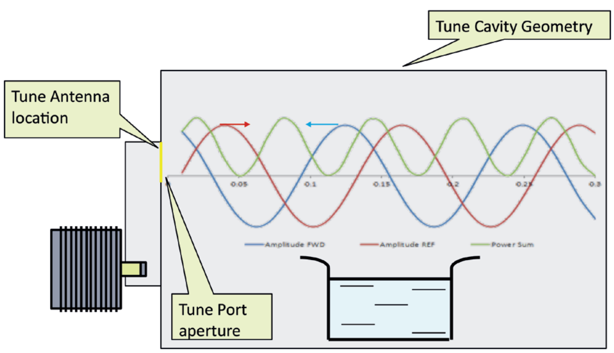
In both the examples given previously, the known shortcomings of the microwave oven are mitigated by recognising the nature of electromagnetic heating and avoiding the potential drawbacks. This can be achieved by reducing the volume of the individual pieces of the food to ensure that a few centimetres of dielectric heating depth is sufficient.

Another way to work around the drawbacks of the microwave oven today is to apply a second source of heat that can act to even out the hotspots. This can be done by using the grill in a combination oven when cooking meat, or by allowing steam to build up around vegetables to equalise the heating effect.

When cooking larger items, it is important to allow enough time for thermal conduction to raise the core temperature to a safe and palatable level. Allowing enough time is as important for homogeneous heating with a magnetron as it is with conventional 'surface only' heating processes.

5 MICROWAVE OVEN CHARACTERISATION

Microwave oven performance is characterised, as most technology is, through the use of standardised tests. Microwave ovens are specified today on their ability to heat one litre of water, which presents a large load to the system and is very easy to heat. Standards and specifications drive the performance optimisation process, which leads to products that are optimised for heating a load that will rarely be encountered in real world usage. Optimisation of conventional microwave ovens has little to do with the magnetron itself, as this has no direct controls. Tuning instead focusses on the geometry of the system, with the goal being to optimise the efficiency and power of energy transfer into a large load located in the centre of a cavity.



Tuning of a microwave oven

Since there is no accurate control of the frequency of operation, these tests must perform well whatever frequency the magnetron operates at from moment to moment.

When evaluating a new technology, with new capabilities and performance goals, revised optimisation procedures may also be required to deliver the full promise. Efficient energy transfer to a one litre load may not be the key metric for future solid state systems, since in the past this has not delivered high performance cooking as a result.

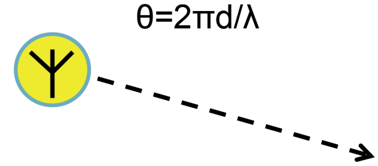
6 MOTIVATING HOTSPOTS AND CAVITY BEHAVIOUR

Simulation of microwave oven cavities and foods can be a complex process, and while good results can be achieved, it is only known to be a good result once it is benchmarked with a real measurement. Once a cavity is built, tests with the real hardware can be significantly faster to run than simulations.

Complex simulations are not required to explain the existence of hotspots in even a simple single port cavity. A modified version of the simple Friis free space formula can be put to good use.

$$P=(\lambda/4\pi d)^2$$

$$\theta=2\pi d/\lambda$$

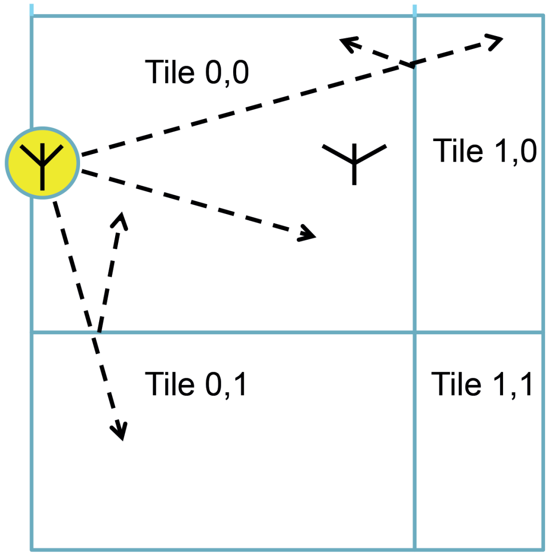


Free space propagation model

Conventionally this is used to predict far field signal propagation in space or under idealised terrestrial conditions. However, by introducing a tile scheme and folding the paths geometrically, a many-reflection version of the Friis formula can be synthesised.

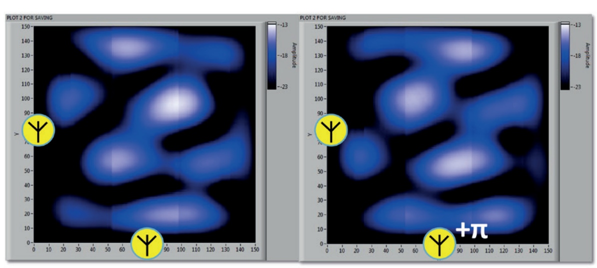
In the simplest form, point A' has the same phase and power as point A, and B' has the same phase and power as at point B.

Extra layers have been added to this model. For example, a pi-radians phase shift for each reflection models the boundary conditions for reflection from a metal plane. A small attenuation factor applied per reflection models reflection losses. Finally beam shaping has been added for each antenna, in this case using a cosine function to weight amplitude with angle. The results shown below are achieved with the model in this form.

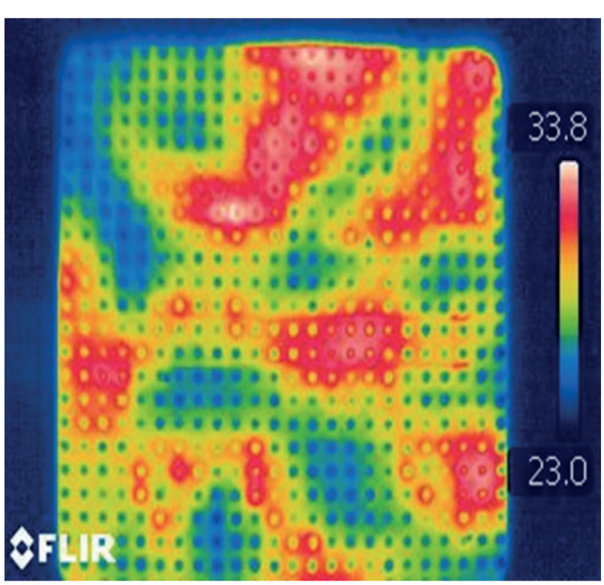


Folded geometry cavity field model

Without resorting to simulation of complex near field effects, highly representative cavity field intensity patterns are predicted, as compared to a thermal capture of a heated display board.



Folded geometry hot spot model of a two antenna system with and without phase shift at one antenna



Thermal image of a detector board

7 SCOPE FOR INNOVATION

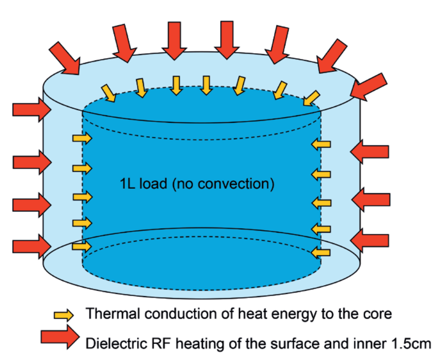
After the brief examination of the behaviour of magnetrons and the optimisation processes used with microwave ovens today, we can examine the capabilities of solid state systems which define the scope for innovative new solutions to RF heating applications. Taken singly, specific characteristics may be useful in some end applications and have no value in others, however together they represent the landscape of new capabilities from which breakthroughs in heating performance will emerge.

7.1 POWER CONTROL

Microwave ovens today implement power control by switching the magnetron on and off over periods of several seconds. A 900W oven when operating at 90W might produce 900W for five seconds and then switch off for forty five seconds. The response time of the valve technology is limited by the time taken for the device to reach its operational temperature, much like an incandescent light bulb. Depending on the type of food being heated, temperature cycling at the edges of the food can cause quality degradation.

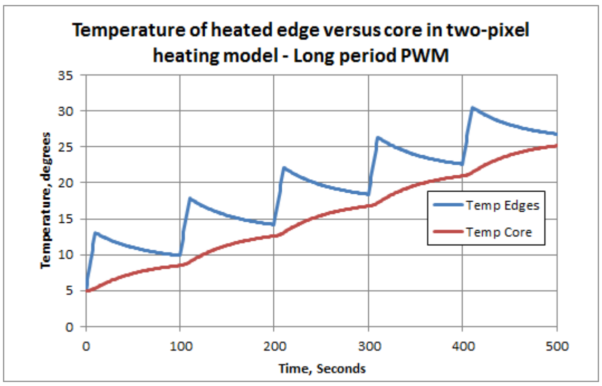
Solid state systems are much more flexible. They can also perform this kind of power control, known as pulse-width-modulation. However, the period of the modulation can be milliseconds or microseconds making the heat delivery much more linear. If required, truly linear power control is also possible.

The effect of the different modes of power control can be demonstrated with a simple two pixel model where a large load is placed in the centre of a cavity, and heated by RF dielectric heating such that the outer 1.5cm is evenly heated. As the outer layer heats, it begins to conduct heat to the core.



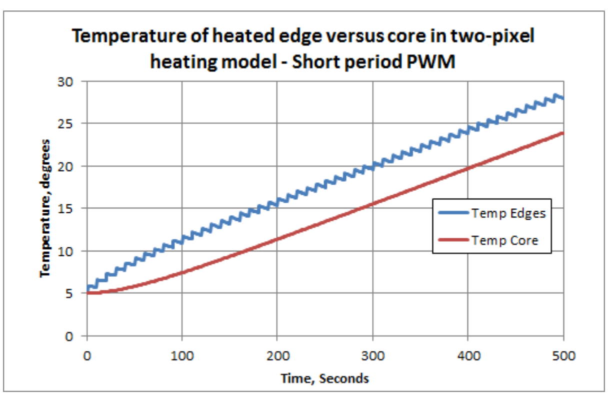
'Two Pixel' RF and conductive heating model

When the load is heated with long period PWM, in this case ten seconds of heating followed by ninety seconds of relaxation, the result is that the edges are regularly heated and then allowed to cool. This creates a saw-tooth temperature progression during heating.



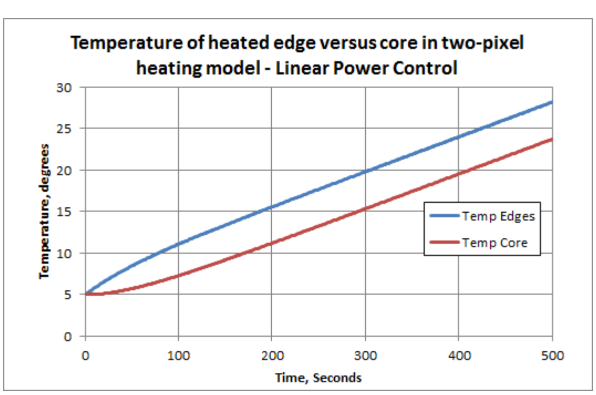
Long term PWM heating prediction

When reduced period PWM is applied, for example one second on, nine off, the resulting temperature profile is closer to the ideal situation.



Short term PWM heating prediction

Indeed, solid state systems can operate with truly linear power control, something impossible with the magnetron, eliminating the over-heat-and-relax cycle entirely for those heating tasks requiring less than maximum power.



Linear power control heating prediction

The discussion on power control is not an abstract one. A conventional oven is infrequently used at its maximum temperature, as different rates of heating are suitable for cooking different foods.

Ultimately it is for the food scientists to fully explain the impact of temperature cycling on food quality, we can simply show that the flexibility of a solid state systems power delivery gives us as the user back the control of power delivery that we take for granted from an electric oven or a gas grill.

One further aspect of the power control of solid state is useful to consider. Both the magnetron and amplifier deliver less power when warm. However, the solid state RF amplifier output can be modulated. In a properly designed solid state heating system, the variation of power and gain with temperature can be corrected with a closed loop power control system. This is common practice in RF communications systems. The benefit of this is that the power delivery will stay the same as the system heats up. A solid state system will cook the second and third meals exactly the same as the first, something todays magnetron based systems fail to do.

7.2 FREQUENCY ACCURACY AND STABILITY

The magnetron is an uncontrolled oscillator, without feedback mechanisms to monitor or set the frequency. Whilst some systems have a mode stirrer which can modulate the impedances seen by the oscillator causing a load pull effect, this is at best a coarse mechanical form of modulation rather than accurate frequency control.

In wireless communications, by contrast, a narrow band of spectrum is allocated for use by a specific system. The narrow band must contain all of the modulated signal power, which makes accurate frequency control essential for spectrum efficiency and error free wireless communications.

When moving from a magnetron based system to one using solid state amplifiers, it is possible to benefit from much of the development into communications technology that has been undertaken in recent decades. Mobile communications is a high volume cost sensitive market that requires accurate phase and amplitude modulation. Use of Solid state amplifiers in RF energy generation enables reuse of modulator technology and digital signal processing techniques which could be a potential game changing approach for any other market segment, including RF heating.

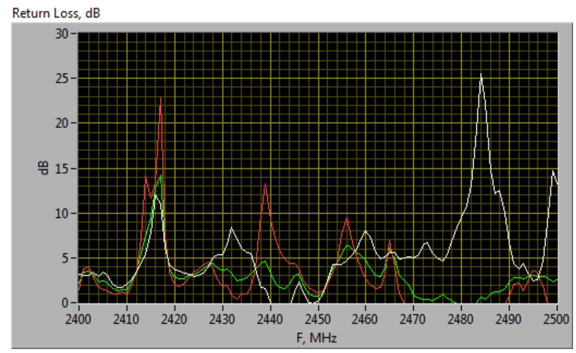
7.3 FREQUENCY TUNING

Bluetooth is a well-known wireless communications system used for short range device to device connectivity. Bluetooth operates in the same band as most consumer microwave ovens. Many networks of Bluetooth devices can coexist in one area without excessive interference through use of frequency hopping spread spectrum. Short packets of data are sent on an agreed channel, after which both the transmitter and receiver quickly hop to a new frequency. In this way, the clashes between asynchronous networks occur only intermittently, allowing higher level link management functions ensure that the functionality of the network continues unaffected. This technology requires low cost frequency agile synthesisers that can change frequency very quickly.

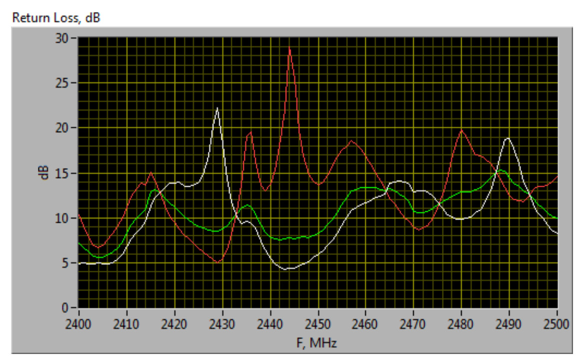
Microwave ovens of the future will reuse this kind of synthesiser technology to spread the power in the frequency domain in the most optimal way to heat a particular food.

Examining the responses of a cavity loaded with different quantities and types of food provides a characteristic fingerprint, which may suggest different frequency and phase states for the heating process. In the following graphs, different loads have been swept over frequency and characterised with a view to choosing one or more frequencies for use in a heating algorithm.

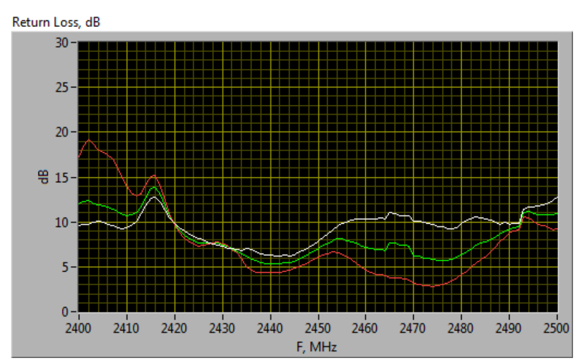
The red and white lines represent the return loss on each port, and green the combined 'compound' return loss. (Return Loss is a measure of how well matched an RF circuit or antenna is. It effectively means 'how much of the power that is transmitted *doesn't* reflect back'. It is an inverse measure of cavity power retention efficiency).



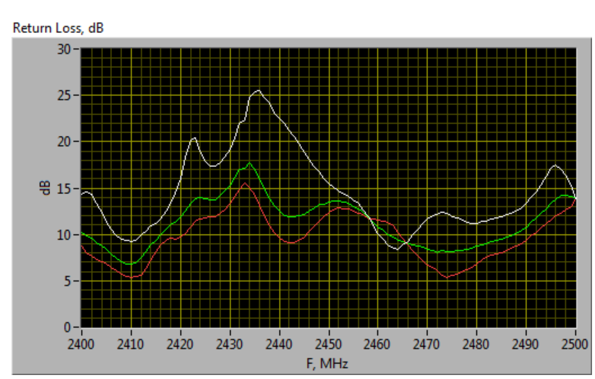
Empty cavity



Cavity containing microwave oven ready popcorn



Cavity containing a distributed load of potatoes



Cavity containing a large water load, centrally located

These plots demonstrate that different foods give different cavity characteristics and are consequently likely to require heating in different ways. This implies that amplifiers used for solid state heating should be able to deliver peak power and efficiency at any frequency in the band, as the cavity power retention optima can occur at any frequency. Although magnetrons are tuned to operate around 2.45GHz, amplifiers should be specified for operation across the whole band.

7.4 MULTI-SOURCE PHASE LOCKING

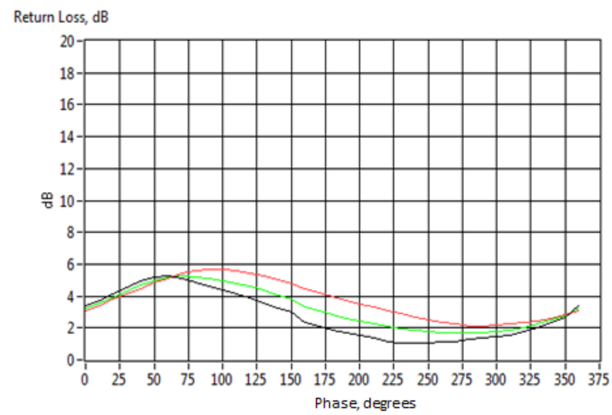
Another aspect of solid state systems, enabled by the synthesisers used in mobile communications or Bluetooth devices, is the fact that many separate sources can emit energy on exactly the same frequency. Systems typically use only a single magnetron, but two, four, or twenty solid state amplifiers can emit energy into one spectrally pure mode. This freedom can result in different product form factors, enable power combining in the cavity, or reduce direct heating effects where the food absorbs the RF energy straight from the antenna rather than allowing it to reflect around the cavity and heat from all sides.

Increasingly the mobile communications world relies on use of multiple antennae to mitigate channel fading and deliver signals to specific users, a problem which corresponds directly to the hotspots encountered in a microwave oven. Antenna diversity has evolved into MIMO, the Multi-Input and Multi-Output communications scheme where signals are sent through multiple antennae to combine optimally at the location of a specific user. Techniques that have evolved to mitigate the negative consequences of a complex multipath propagation environment in mobile communications may also have value in an oven.

7.5 PHASE CONTROL

With multiple sources come additional possibilities for control of the signals and resulting field strength distribution inside a cavity. In addition to controlling frequency, the relative phase of the signals can be adapted. As with frequency, phase has a direct effect on the energy distribution in the cavity, moving the hot spots but also changing the return loss on each RF port.

This may seem counter intuitive, but it is a real phenomenon. Due to the coherent nature of the signals, the amplitude and phase of signals emitted at any one port will affect the field distribution throughout the entire cavity. Consequently, changing phase on channel 1 will change the power reflected from all other channels. Since all port return losses change, the compound return loss will also change.



Port 1, 2 and compound return loss v phase of channel 2

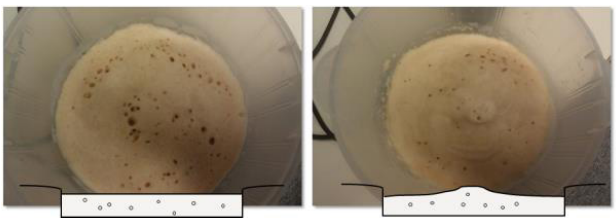
7.6 CAVITY SENSING AND ALGORITHMS

Working out how much power is reflected back from the cavity, and adaptively managing this, provides a degree of heating process control unavailable with open loop systems. With the additional control and feedback from the cavity comes the requirement to define a heating strategy, or algorithm.

In some cases the goal might be to sweep phase and frequency (and therefore field distribution pattern) methodically over the widest range of states. In other cases it might be best simply to find the highest return loss modes to ensure the maximum power is retained within the cavity where it is available for heating the load.

There are often a number of food-specific programs available on microwave ovens, however the engine of the oven has only two states, on and off. Future microwave ovens will be able to tailor the frequency and phase and power to a specific task, giving millions of states that can be built into complex sequences for heating different types of food.

By way of example, the different profiles of cooked pancake batter shown were achieved by using the spectrum firstly in an even way across all frequencies, and secondly by adaptively biasing towards only modes with very good cavity power retention.



A thick pancake batter demo load heated first using all frequencies evenly, and secondly with an adaptive heating algorithm biased to use only the best modes for efficient cavity power retention.

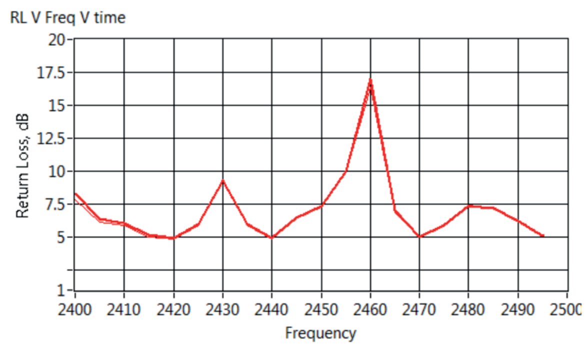
The algorithm that biased towards only efficient coupling of energy into the cavity and load heated the centre of the batter most directly, causing the middle to rise faster than the edges. The algorithm that used all frequencies rose evenly.

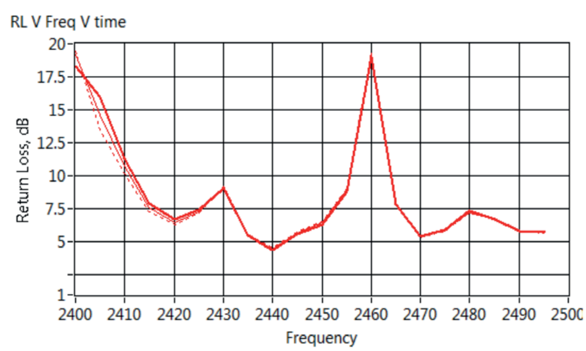
Many RF Engineers will already be familiar with the vector network analyser. This is a measurement system that can characterise the amplitude and phase of signals into, through and back from active and passive circuits. This is a key instrument for design of filters, amplifiers, mixers and other electronic building block circuits for communications.

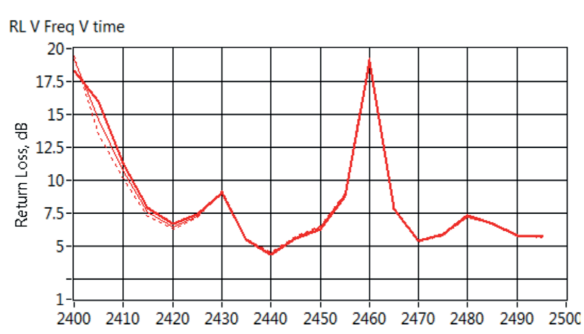
NXP's solid state heating demo systems are effectively un-calibrated high power vector network analysers. The food can be sensed as part of the microwave oven cavity and changes over time can be measured.

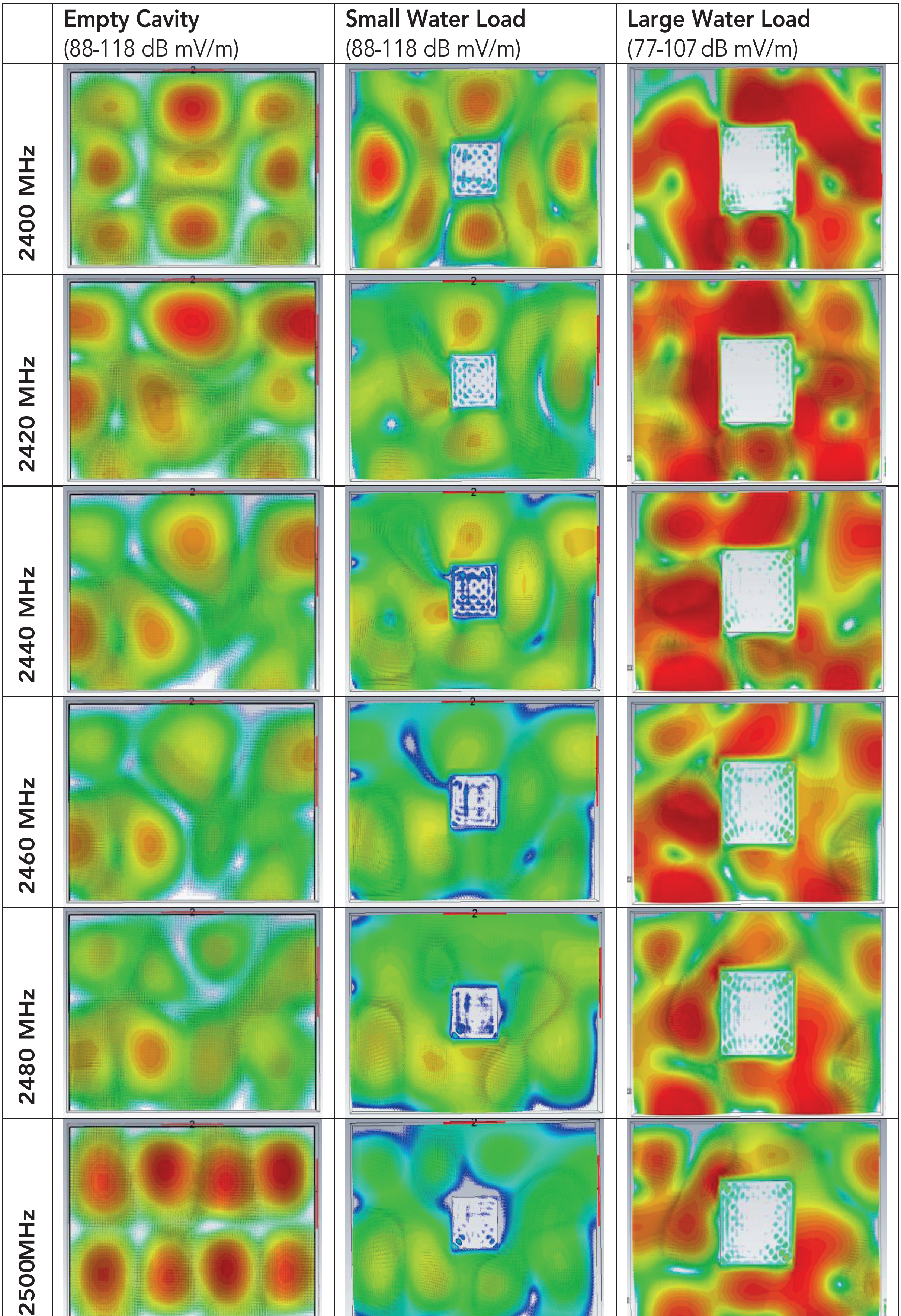
Today many microwave ovens use a moisture sensor to provide feedback from the cooking process. Solid state systems provide an entirely new dimension to sensing. Simply measuring how much of the available RF power is reflected from the cavity allows a system to modify cooking time appropriately. Further, foods are complex substances that are modified by the heating process. Turning a microwave oven into a measurement system raises additional possibilities. The following plots show a sequence of frames of return loss measured over frequency at evenly spaced times through the cooking of a beef burger.

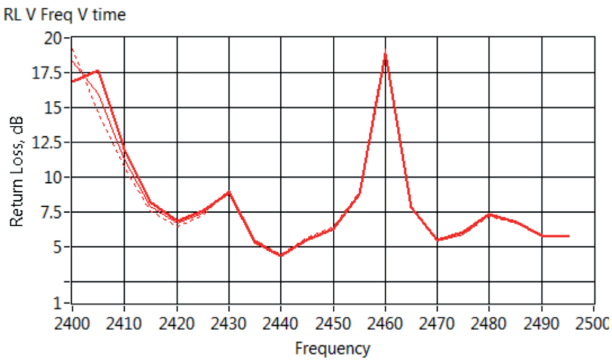
Changes in the behaviour of the cavity are clearly visible at some frequencies as the food changes during the cooking process. Other frequencies remain largely unaffected. Different foods generate different changes in the cavity fingerprint during heating. Reflected phase also varies as the cooking process evolves.








Empty Cavity
(88-118 dB mV/m)
Small Water Load
(88-118 dB mV/m)
Large Water Load
(77-107 dB mV/m)
2400 MHz
2420 MHz
2440 MHz
2460 MHz
2480 MHz
2500MHz



Evolution of return loss V frequency during the cooking of a beef burger

7.7 LIFETIME AND RELIABILITY

Lastly, but not least important when considering switching to a solid state RF energy delivery mechanism, is reliability. Magnetrons, like lightbulbs, have a limited lifetime. Consumer magnetrons may last for five hundred hours, industrial grade parts perhaps a year in continuous operation. Mobile communications systems must work reliably in the field for fifteen years, 24/7. The base station must work on the last day as well as it did on the first. Tests on our own ovens have shown that the power output is reduced by a third long before the magnetron fails completely. Potentially one of the barriers to integration of RF heating into high performance cooking systems has been the low lifetime and low reliability of the magnetron. The typical buyer is likely to have a different expectation of lifetime and reliability from a high end range oven than a counter top microwave.

8 EMPTY V LOADED CAVITY

The hotspot model presented previously is based on superposition of many reflected waves inside a cavity. This model demonstrates a highly characteristic pattern of field strength which is affected by the phase and frequency controls available with solid state cooking systems. These patterns can be seen in practice by placing a number of neon lamps inside the cavity and applying power. This idea has been extended to create field pattern detector boards with arrays of LEDs. Three colours are used, each connected to a short antenna in the X, Y or Z polarisation planes.

When frequency and phase are swept, this detector provides clear visual evidence of the effect on the field distribution of the controls available with solid state systems.

NXP demo system showing an LED tri-colour field detector board in use

However, this simple and practical demonstration does not tell the full story. Simulations of cavities in an empty state and with small and large loads show very different patterns of field intensity. In the simulation results illustrated, an empty cavity displays a strong mode pattern at 2500MHz. However placing a small load in the cavity collapses this mode entirely.

In general, the fields in an empty cavity are unrelated to the fields of a loaded cavity. This renders the LED demonstration a handy visual aid for demonstrating the control effectiveness of a solid state oven, but not a useful tool for working out how best to heat food.

The heavily loaded cavity demonstrates another important behaviour. The field patterns display relatively larger areas at peak field strength. This might at first glance seem counter intuitive. Why would the fields be more evenly distributed in a heavily loaded cavity? As in the case of outdoor RF propagation, the superposition effects can be both constructive and destructive. Multi-path radio communication signals can occasionally combine in phase to create a location of especially high signal strength. However, in general the field components will not all arrive in phase and will be partially destructively combined.

In situations with many signal paths between two points, as in a city landscape or a microwave oven cavity, damping the interactions and reflections can remove the opportunity for multipath fading. The same mechanisms that are responsible for much of the complexity in short and medium range communications channels are also responsible for the hotspot patterns in a microwave oven cavity.

Observation of this effect quickly teaches the user that large loads, relative to cavity size, are easy to heat. Increased cavity damping leads to reduced interaction between antennae, and less variation of field patterns with frequency or phase shifts. Taken to an extreme, if a two channel solid state microwave oven was entirely filled with water, the emitted power would dissipate within a few multiples of the electromagnetic energy penetration distance of each antenna. The cavity would cease to respond as a resonant structure at all, and signals from the two antennae would not interact in any measurable way. Phase and Frequency would cease to affect the heating process.

When a large load couples energy strongly from the field in this way, there may be less control, but by definition these loads are easy to heat. Conversely, we should expect that the precision and controllability of a solid state heating system is most valuable for tackling the real world heating jobs that we as consumers might more frequently undertake. We might never operate an oven empty, and rarely load it to its maximum to try to boil a large volume of water. Most real world tasks fall in between these extremes, where the uncontrolled magnetron is less effective as the heating patterns are still strongly modal and frequency dependant.

It is interesting to recall that the standardised test used for specifying magnetron based microwave oven power output and efficiency uses the one litre water load as shown in the simulation results. For a system with limited control, it is best to specify power and efficiency in a situation where control is less critical.

9 FREQUENCY BAND CHOICES

One important consideration when applying solid state heating technology is the frequency band to use. Electromagnetic absorption by dielectrics varies significantly with frequency. EM penetration depth estimations (to 37% signal power) have been performed for some example foodstuffs for three license exempt frequency bands currently in use for dielectric heating applications around the world.

Another key aspect of microwave oven functionality is evident from the table. 2.4GHz microwave ovens cannot, as many assume, heat from the middle of the food. Heating occurs predominantly within the first couple of centimetres of the surface of the food. This is deeper than heating by conventional means such as infra-red or hot air convection, but falls far short of the ideal goal for a heating appliance of homogeneous volumetric heating.

The controllability of solid state heating systems is vastly enhanced compared to magnetron based ovens, and cavity feedback is a vital new step in enabling better heating algorithms, but physics limits the capabilities of every new technology. Understanding these boundaries is also key.

Food	εr	Tan-δ	433 MHz	915 MHz	2450 MHz
Raw Pork	38	0.37	4.67	2.21	0.83
Cooked Beef	40.5	0.28	6.48	3.07	1.15
Raw Beef	49	0.29	4.88	2.31	0.86
Cooked Cod	47	0.26	6.92	3.27	1.22
Mashed Potato	64	0.33	4.04	1.91	0.71
Peas	62	0.27	5.43	2.57	0.96
Soup	70	0.27	5.17	2.457	0.91
Gravy	73	0.32	3.95	1.87	0.7
Carrots	70	0.26	5.17	2.45	0.91
Water	77	0.14	8.59	4.06	1.52

(http://www.sfu.ca/phys/346/121/resources/physics_of_microwave_ovens.pdf)

Both infra-red and hot air convection heating technologies can achieve surface temperatures of 250 degrees Celsius or even more, delivering a result that is pleasing to our palate but requiring significant time for heat energy to be conducted from the surface to bring the core of the food to a safe temperature of seventy degrees or so

EM heating on the other hand acts mainly (but not solely) on the polar water molecule, which can limit the maximum temperature achievable due to the evaporation of the substance that couples power from the field. An ideal combined heating effect can be foreseen when RF heating is used to bring the core temperatures rapidly to the desired level, and hot air convection or infra-red heating methods are used to create a pleasing surface texture, even surface heating and a desirable taste.

Having proposed this optimal combination heating mechanism, it can be seen that the more evenly and deeply the EM energy penetrates the food, the less time will be needed for a desired quality of result. More even volumetric heating means less time is needed for thermal conduction to complete the job of spreading the heat from strongly heated areas to more weakly heated areas. In turn faster and more even heating mechanisms mean less opportunity for the food to dry out or overheat in the more directly heated areas.

These principles hold true even for conventional cooking techniques, which is why it can be difficult to deliver a consistently succulent roast beef joint or a truly moist festive season turkey. The energy is not homogeneously applied, and long cooking times are required which can dry the most directly heated areas.

To achieve the goal of more even, deeper volumetric heating to best complement – and accelerate - a hot air or infra-red cooking system, a lower frequency may be desirable simply due to the physics of RF and dielectric interaction.

Magnetrons are resonant structures and therefore rapidly increase in size, cost and weight when designed for lower frequency operation. Solid state amplifiers are still very realisable at a tenth of the frequency of today's consumer microwave ovens, and to sweeten the deal, the achievable electrical efficiency of these amplifiers increases significantly.

10 CONCLUSION

When microwave oven development engineers begin to work with solid state cooking systems, the questions they ask are illuminating.

- If the power reflecting from the oven varies depending on where we put the food and what shape it is…
- If we can only effectively heat a few centimetres near the foods surface…
- If small loads need accurate tuning where large loads do not, but we are optimising cavity geometry for large loads…
- Then how have we ever developed ovens that work?

As users, perhaps, we may feel that we already know the answer.

Solid state energy delivery addresses many of the drawbacks associated with microwave ovens using magnetrons. As discussed in detail in this article, the new technology brings with it a landscape of new design choices, techniques and capabilities.

- Enhanced lifetime
- Frequency accuracy of a few PPM
- Frequency tuning and fast frequency hopping
- Phase locking of multiple sources
- Phase control
- Enhanced power control through Linear and fast PWM techniques
- Closed loop power control enabling repeatability
- Cavity reflection sensing and feedback of power and phase
- Energy generation at new frequencies with compact form factor

Taken together, application of these new techniques in the cooking and heating products of the future will allow product differentiation by performance rather than styling.

Instead of innovation in microwave heating being focussed on food additives and packaging, innovation will soon be all about how to build the best new RF engine, and learning how to use it.

www.nxp.com

Date of release: March 2015

Document order number: 9397 750 17647

Printed in the Netherlands